Different dynamic models for the study of ultrasonic wave dispersion for mechanical characterization of construction materials

Nicola De Fazio*[1], Luca Placidi[2], Andrea Tomassi[2], Bilen Emek Abali[3], Aguinaldo Fraddosio[4], Anna Castellano[4], and Francesco Paparella[4]

[1]University of Catania, Engineering Faculty, Piazza Università, 2, 95124 Catania – Italy
[2]International Telematic University Uninettuno, Engineering Faculty, C.so Vittorio Emanuele II, 39, 00186 Roma – Italy
[3]Uppsala University, Department of Material Science and Engineering, Box 35, 751 03 Uppsala – Sweden
[4]Polytechnic University of Bari, Engineering Faculty, Via Edoardo Orabona, 4, 70126, Bari – Italy

Abstract

In this study, we explore the dispersion relation, i.e. the dependence of the plane wave velocity with respect to the frequency, for longitudinal ultrasonic waves from both experimental and modeling points of view. For the modeling point of view, we start considering a 1D medium with different constitutive properties: from one hand we consider the non-dissipative strain-gradient elastic model and from the other hand the dissipative viscoelastic model.
1. **Dispersion stemming from material microstructure**: At low frequencies, the phase velocity correlates directly with material stiffness. Conversely, at higher frequencies (i.e. at low wavelengths), the phase velocity is influenced by the material's microstructure. The transition between these two velocity regimes occurs within a frequency range proportional to the characteristic length of the material.

2. **Dispersion arising from material internal viscosity**: Higher internal viscosity enhances material stiffening under dynamic loading, whereas lower viscosity necessitates higher frequencies to observe significant velocity variations.

We derive the governing equations for both cases with the extended Rayleigh-Hamilton principle. The analysis shows good agreement with the experiments and further experimental investigations are designed for a clear and quantitative identification of the dissipative contribution.
Moreover, the governing equations of motion, material constitutive relations, and boundary conditions are formulated and solved in both 2D and 3D domains to account for the real experimental conditions and reduce approximation errors. A time integration scheme is employed, coupled with variational formulations and finite element methods (FEM), to establish a relationship between wave velocity and material parameters, similar to the solutions for 1D models. We start with isotropic, homogeneous, and linearly elastic materials and then we add viscosity and microstructure as for 1D models. Validation was conducted

*Speaker

using experimental data from concrete specimens tested in a controlled laboratory setting. The results confirmed the model's accuracy in predicting wave velocity and dynamics.